"Modification of Driver Behavior Based on Information from Pedestrian Countdown Timers"

BY

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ABSTRACT

Pedestrian countdown timers (CDTs) are promoted as a means of improving pedestrian safety at intersections. However, there are concerns that drivers view the CDTs when approaching the intersection and use that information to drive more aggressively - an unintended consequence that is detrimental to safety. Pedestrian CDTs have been in use in Lawrence, Kansas for at least three years, and so any novelty effect should have passed, allowing for an accurate analysis of the long-term effects of the devices on traffic.

Four intersections along an arterial corridor in Lawrence were studied – two with CDTs and two with flashing hand pedestrian signal heads. Continuous speed data were collected on approaching traffic and analyzed to determine if there were changes in speed between 400 ft upstream from the intersection (the point when the CDT information could be read by drivers) and the intersection stop bar. Additionally, the ultimate decision of the drivers (whether they stopped or not) was recorded.

Analysis revealed that drivers were less likely to increase their approach speed when a CDT was present. Additionally, some drivers began to slow to a stop *before* the beginning of the amber phase when CDTs were present. These findings indicate that drivers use the information provided from pedestrian CDTs to improve their driving decisions. Even though the CDT information was not intended to be used by

drivers, it appears that they are indeed doing so in a way that results in safer driving actions.

ACKNOWLEDGEMENTS

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CHAPTER 1: INTRODUCTION

Pedestrian signal heads (PSHs) provide pedestrians with guidance during crossing maneuvers at intersections. The *Manual on Uniform Traffic Control Devices* (MUTCD) defines a PSH as "special types of traffic signal indications exclusively intended for controlling pedestrian traffic (1)".

A PSH can come in multiple designs; the flashing hand symbolic head or the flashing hand with a countdown supplement. They may also include additional modifications such as audible tones and/or vibrotactile symbols for the hearing impaired. The PSH must be mounted near the crosswalk within a range of seven to ten feet in height.

A countdown timer (CDT) is an addition to the standard PSH which helps a pedestrian decide how much time is left before the walk phase ends. In the case of the CDT, the numerical symbol must be more than six inches in height on a black background to increase visibility. During the pedestrian clearance interval, the CDT counts down numerically in seconds remaining while a flashing hand is displayed. Once the countdown reaches 0, then the steady hand is displayed.

This thesis follows the style and format of the *Transportation Research Record*.

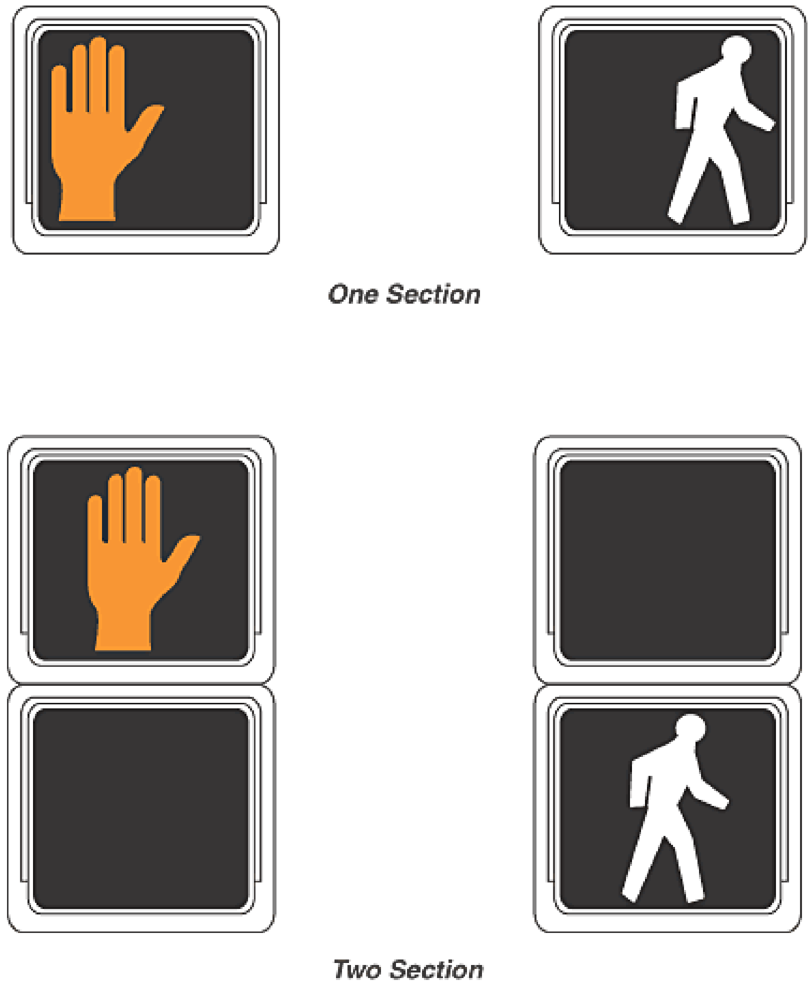

Figure 1. Typical PSH (1)

Background

There are 51 traffic signals in the city of Lawrence with a CDT. Of those 51, two are mid-block pedestrian crossings. Countdown timers have been installed progressively for the past three years by the city engineer so any novelty should be eliminated.

Every new traffic signal installation now gets a CDT regardless of pedestrian volume. The model which the city uses has 8-inch tall numbers. Starting this year, they will start installing models with 10-inch numbers.

Figure 2. Countdown timer at Alabama Street and 23rd Street

Other countries have experimented with adding supplemental information to help the driver make better decisions when approaching signals. There have been systems involving flashing amber or green before the onset of red. Another method, which more closely relates to this topic, is one found in Malaysia shown in Figure 3. The system is a large CDT on the mast arm which counts down the time remaining for the green phase *and* the red phase. The type used in this configuration is used as additional information for the driver, not the pedestrian. This type of CDT is explicitly mentioned by the FHWA as an unapproved method and should not be experimented with (2). Therefore, the CDT's mentioned in this study all refer to the CDT in the PSH which are intended for pedestrians, not drivers.

Figure 3. A traffic signal found in Malaysia showing a CDT intended for driver use

Problem Statement

Research on CDTs has been largely limited to how CDTs interact with pedestrians at crosswalks (3). However, the typical installed location of all PSHs (including CDTs) is in view of drivers, so it is possible that drivers use the PSHs to change their driving behavior. There has been little research done on CDTs relating to modifying driver behavior. Research on CDTs is increasingly important as CDTs become more frequent. There also has been some thought to mandate the installation of a CDT in all new locations in place of a traditional flashing hand PSH.

There have been a few studies into driver interaction with CDTs (4) but they have been largely based on fragmented data. A driver reading the CDT, then increasing speed to avoid stopping for a red signal would be an unintended and undesirable consequence of the presence of pedestrian CDT installations, and a better understanding of how drivers react to them is needed.

Research Objectives

The goal of this research was to identify driver behavior modification based on the information presented by pedestrian CDTs. Driver behavior was observed using a LIDAR device to measure speed of vehicles relative to their distance and time remaining on the PSH. The research objectives were:

- To capture driver behavior relative to the PSH at intersections equipped with CDTs and at intersections equipped with flashing hand PSHs.
- To relate the speed and distance data to the PSH.
- To determine if there is a driver behavior difference between CDTs and the flashing hand PSH.

Research Benefits

This research work serves to answer the question whether or not CDTs modify driver behavior. If CDTs do modify driver behavior, does the installation of CDTs cause a negative impact in the safety of the intersection? The results of this thesis will present insight into the impacts of CDTs.

Thesis Organization

The thesis is organized into six chapters. The first chapter of the thesis provides the background for the thesis. It also lists the problem statement, research objectives, and benefits. The second chapter of the thesis reviews the history, use, and previous research into flashing hand and CDT PSHs. The third chapter details the methodology used for this thesis. This includes the description of the study equipment, study sites, and statistical design. The fourth chapter describes how the data was reduced. The fifth chapter describes the data analysis. The sixth and final chapter lists the conclusion and recommendations for future work.

CHAPTER 2: LITERATURE REVIEW

The first step in this research was to conduct a literature review to determine the findings of previous related studies. Previous research was examined to provide the history of the PSHs and a better understanding of the driver approach behavior. The review also served to determine what deficiencies currently exist, which can be filled in by the research reported in this thesis.

The literature review was divided by subject. First, a background in the history and use of the PSH; second, a review of the contributing previous research done with regards to CDTs; third, a review of driver approach behavior; and fourth, a brief review of red- and yellow-light running.

This literature review was not intended to envelop all CDT research, but was intended to provide a summary of important work, which contributed directly to the objectives of the thesis.

PSH History and Use

PSHs have been used for pedestrian safety since the late 1930's in New York City (5) when they were seen as a solution to minimizing death and injury among pedestrians. Initially, the PSHs were non-directional with the traffic signal cycle including an all-walk or scramble phase, shown in Figure 4. Today, scramble phases are typically only found at high pedestrian volume locations because they increase the cycle length of a traffic signal. The "walk" function was first used as early as 1934 in Chicago along with directional traffic signals.

Figure 4. A scramble phase found in downtown Reno with a diagonal pedestrian movement

Figure 1 is a typical flashing hand PSH according to the MUTCD. The “walking man” and “flashing hand” symbols must be completely homogeneous on an opaque background. During the walk phase, the walking man is displayed on the PSH. At the beginning of the pedestrian clearance phase, the flashing hand appears and must flash at a rate of 1-1.2 seconds per flash (1). The size of the symbols depends on the distance from the beginning of the crosswalk, but the minimum is no less than six inches in height.

Figure 5. Typical CDT

For CDTs, such as the one shown in Figure 5, similar requirements to the standard PSH apply per the MUTCD (1). The figures must be at minimum 6 inches tall on an opaque background. In addition, the countdown function must be directly beside or below the walking man/ flashing hand symbol. The countdown itself must count down to the end of the pedestrian change interval (1). Once it concludes at the zero “0” numeral, the countdown display must remain blank until a renewal of the pedestrian phase. The indication of the “0” on the countdown also requires that the flashing hand changes to the steady upraised hand.

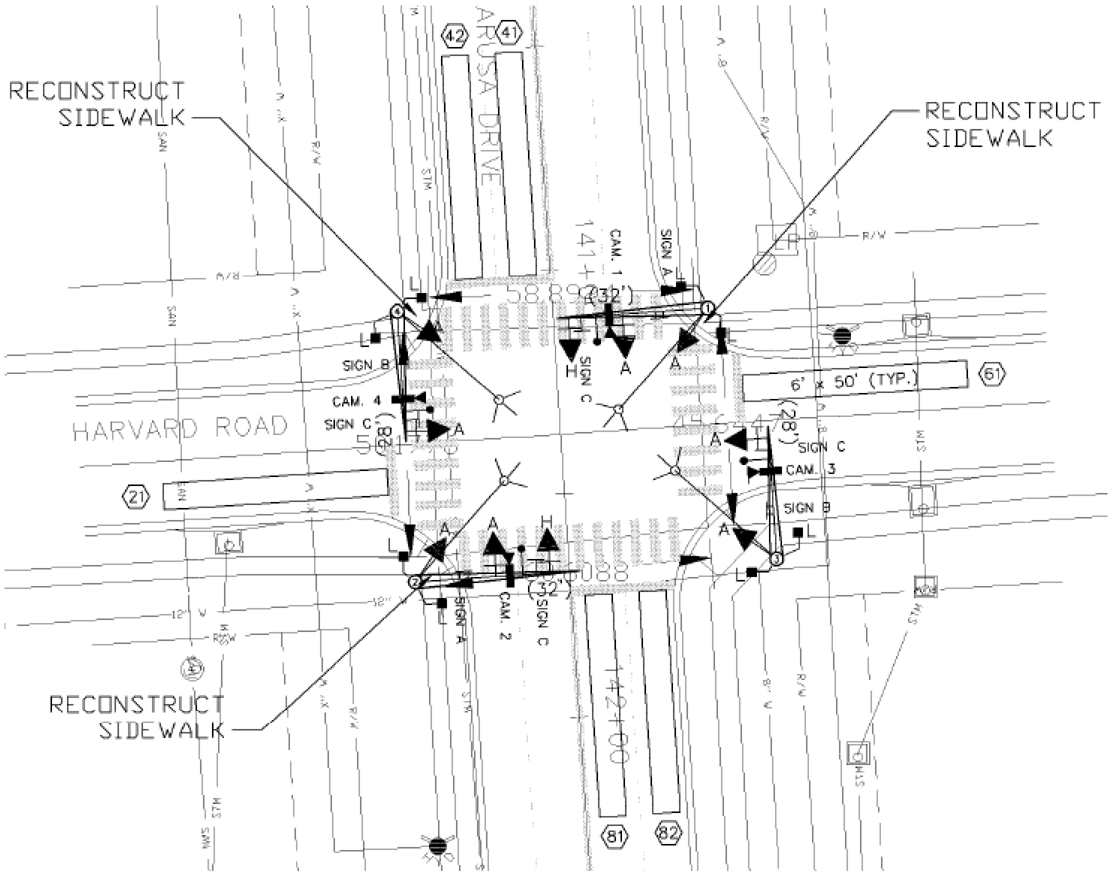

Figure 6. Typical intersection diagram showing PSH locations.

Figure 6 shows a typical drawing of a signal heads where a PSH would be installed. In the drawing, the PSH is labeled as "L" and installed on the pole for the traffic signal. The PSH is directional and so must be positioned in the direction of the concurrent pedestrian phase. The PSH has to be visible from a maximum distance of 10ft from the end of the crosswalk. In instances where the start of the crosswalk is farther than 100ft, the PSH must increase the characters to a minimum of nine inches. There were no instances of a crosswalk being longer than 100ft in this study; however, all PSHs contained an 8-inch character height. The standard mounting height of the PSH is within the range of 7ft to 10ft. This is intended to prevent a PSH from causing interference with pedestrians and maximize visibility.

When the pedestrian phase is not automatic, regulation signs, such as those shown in Figure 7 and Figure 8, are installed above the pushbutton. The presence of a CDT requires the use of the R10-3e regulatory sign, which includes additional information on the information presented by the CDT. These signs are small enough to be read by pedestrians close to the sign and should be nearly impossible for passing motorists to read. Any modified behavior from the passing drivers is either intuitive or from the experience of using a CDT as a pedestrian.

Figure 7. Regulatory signs associated with CDT PSHs

Figure 8. Typical regulatory signs associated with flashing hand PSHs

A concern associated with the installation of a CDT arises if a pre-emption phase is used in the traffic signal timing. A pre-emption phase occurs when an outside influence such as a fire truck or railroad crossing cause the timing of the traffic signal to change from its typical timing pattern to one which prohibits certain movements. The most common pre-emption scenario is when an emergency vehicle passes the intersection and the signal automatically gives right of way preference to the emergency vehicle. Guidance by the MUTCD states "the countdown pedestrian signal display should be discontinued and go dark immediately upon activation of the preemption transition (1)." During data collection, some instances of pre-emption were witnessed but no pedestrians were adversely affected.

Previous CDT Research

Previous research by the Minnesota Department of Transportation found that the proportion of pedestrians, who were successfully able to cross five urban intersections in appropriate times, increased from 67 to 75 percent after the installation of CDTs (6). Additionally, when interviewed, an overwhelming majority (92 percent) of those pedestrians found the CDTs helpful in making their crossing decision. Indeed, there is strong evidence that providing pedestrians with any kind additional information beyond the traditional WALK/DON'T WALK indication can have a beneficial change in safety (7). Other researchers have been able to show a significant reduction, 52 percent, in pedestrian-involved crashes at intersections where CDTs have been installed (3).

It was found in many states and jurisdictions that laws exist stating that pedestrians must start the crossing during the walk phase. If the pedestrian starts crossing at any time when the upraised hand is presented, flashing or steady, the pedestrian is breaking the law. The law's existence is likely based on the idea that pedestrians will not know how long they have to cross the intersection and if they cross at a standard PSH with the flashing hand, they may still be in the trafficway when the pedestrian phase terminates, causing conflict. Although this law may have been created before the advent of the CDT, the law still exists.

There have been some studies of the pedestrian compliance rate of CDTs (8,9). Pedestrians tend to like the CDT better than the standard PSH and research shows CDTs increase pedestrian capacity. The first study (8) found a decrease in compliance after the CDTs were installed meaning that pedestrians were more likely to start their movement after the legal time to do so had passed. Both studies used the definition of compliance which related to the above stated law, but nevertheless, it was recommended by authors of the study (8) that CDTs not be installed because of the compliance issues. It was theorized by the authors of the study (8) that the reduced compliance rate was caused by eliminating the uncertainty of time remaining in a pedestrian phase. The second study (9) found that compliance increased in six of the 20 pedestrian crosswalks and compliance decreased in two of those crosswalks.

However, because drivers can also see these indications, there are concerns that driver behavior may also change in a way that degrades safety (9,10). While there have been many studies that examine how pedestrian actions are changed with the installation of CDTs, only a few studies have explored how these devices might change the behavior of drivers passing through the intersection.

A study done in Maryland (9) used a similar approach to this thesis to determine if driver approach speeds changed after a CDT was installed. This study was a before and after study on five intersections in Maryland, which used a radar gun to determine driver's speeds within 400 ft of the stop line. The comparison of speed before CDT installation to that of after was done using a Student's t-test. It was found that only one approach out of the five intersections yielded a statistically significant reduction in average approach speed. All other approaches did not have a statistically significant change.

One study found that drivers at one intersection with CDTs were less likely to enter an intersection at the end of the amber phase than those at another nearby intersection without the CDTs (11). In that study, 42 drivers at non-CDT traffic signals entered into the intersection between the amber and red phases where there were only two instances at CDT-equipped traffic signals. Furthermore, it was found that drivers exhibited different stopping behavior at the two intersections, which could indicate different braking habits exhibited by drivers based on the type of information available to them.

In another study that examined driver behavior, reported red-light running instances were reduced from 2 percent to 1 percent, but the authors conjectured that this was due to drivers accelerating because of the CDTs and avoiding the red phase altogether (3).

Another study on CDTs which concentrated on red-light running and yellow-light running (8) found that there was no difference in instances of red- and yellow-light running at traffic signals before and after the installation of a CDT. The study also examined a parallel study in which CDT locations were compared to five non-CDT traffic signals. Again, the instances of red- and yellow-light running were not statistically significant between the two different types of PSH intersections. The authors concluded that the installation of the CDTs did not adversely affect the safety of the intersection. The other study (8), which was also a red- and yellow-light running study based in California, found similar results in that there was no observed negative behavior posed by the installation of CDTs. The only difference in the second study from the first study (11) is that the second study was a before and after study whereas the first study was a parallel study.

Driver Approach Behavior

The term “dilemma zone” is defined by the ITE handbook (12) as a distance range where a vehicle approaching the traffic signal can neither stop comfortably nor safely proceed through the intersection. It can be caused by multiple factors such as visibility of the traffic signal and the length of the intersection clearance phase. Multiple studies have observed the dilemma zone as a safety hazard in which understanding is key to mitigation.

Some researchers have found that the dilemma zone is not static, but instead, dynamic (13). Their dilemma zone study found that in six intersections, the dynamic dilemma zone was within a range from 98 ft to 606 ft upstream of the stop line depending on the approach speed of the vehicle (32 and 54 mph, respectively). Corresponding with their speed was the classification of drivers as conservative, normal, and aggressive. Ultimately, the study found that aggressive drivers, with higher approach speeds, had a much larger dilemma zone.

A second study regarding dilemma zones (14) evaluated the probability of a vehicle stopping at the stop line when presented with the amber onset while approaching the traffic signal. The researchers also termed the phrase "indecision zone" also known as "Type II Dilemma" in another paper (13). The author further explains the indecision zone as: "The area upstream from the stop line between which 10 percent and 90 percent of the drivers will stop in response to the yellow indication (14)."

This area is often found in a time range of 2.5 to 5.5 seconds upstream of the traffic signal stop line. The indecision zone is an area which exists at all traffic signals whereas the dilemma zone is argued to be largely a timing flaw in some traffic signals.

The data obtained in the study (14) are shown in Figure 9. The graph represents the probability of a stop result as a function of travel time upstream of the stop line. The downward trending line, "Last to Go," are for vehicles which will go through the intersection. The upward trending line, "First to Stop," is those vehicles likely to stop at the stop line.

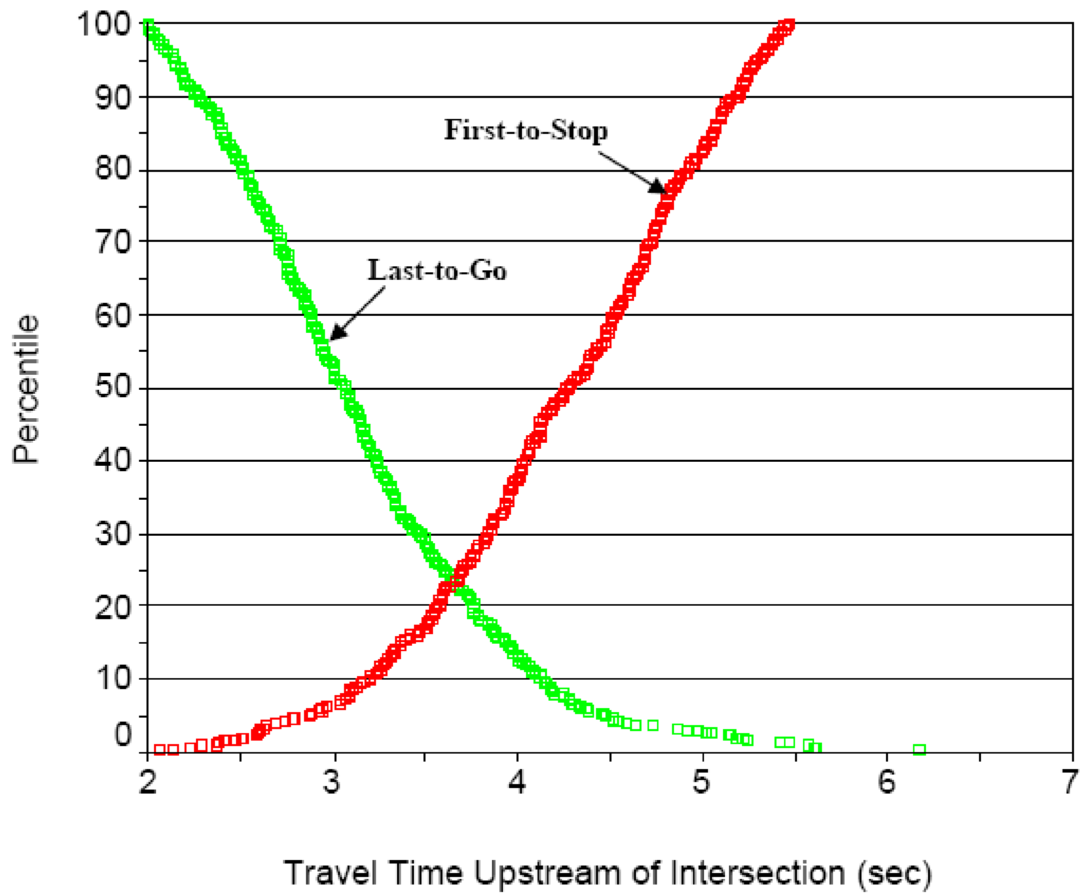

Figure 9. Analysis of indecision zone distances based on travel time upstream of the intersection (14)

Red- and Yellow-Light Running

Some studies have observed the tendency of red- and yellow-light running at various traffic signals. Red-light running is thought to be a consequence of multiple factors converging at one particular moment. The variables include the driver, the distance upstream upon onset of amber, the speed upon onset of amber, other drivers, and weather. The driver, distance, and speed upstream of any vehicle are particularly interesting with relation to this study.

The stop/go decision of a driver may be predicted by the distance upstream of intersections. One study on red-light running (15) developed a model to predict red-light running events based on similar intersections to this study. The approach speed limit was 45 mph with a 4.3-second amber phase. It was found that 80 percent of drivers would go if presented with the amber phase less than 287.5 ft upstream of the stop line. When drivers were presented with the amber phase at more than 372.5 ft upstream of the stop line, 92 percent of drivers would stop. If the driver was 287.5 to 372.5 ft upstream of the stop line, 50 percent of drivers would go.

That study also related red-light running to the speed at which a vehicle was traveling upon amber onset. If a vehicle was traveling above the speed limit at the distance 287.5 to 372.5 ft upstream, the driver was more likely to proceed through the intersection when presented with an amber phase. That range was responsible for 90 percent of the red-light runners observed in the trial, leading the authors to conclude that this was the indecision zone for the 45-mph approach speed.

Summary

Many significant points were identified through the literature review. Many of those points impacted ways to develop this study to answer if and how a driver may modify their behavior.

- CDTs are part of an ever-evolving system to control pedestrian traffic at traffic signals (5, 6, 7, 8, 9).
- Compliance by pedestrians can sometimes decrease at locations with CDTs (8,9) although increases have also been found (9) and the interpretation of the definition can affect some compliance results.
- Installation of the CDT had been associated with a decrease in pedestrian-related crashes (9).
- Drivers in a before and after study (9) were found to decrease their average approach speeds.
- Instances of yellow- and red-light running decreased when CDTs were present (8).
- Every traffic signal approach has an indecision zone where a driver can safely make either a stop or go decision but not every signal has a dilemma zone (14).
- An indecision zone is typically found within 400 ft upstream of the stop line at approach speeds of 35-45 mph (15).

The information in the literature review was useful in determining the best way to study driver behavior, which is presented in Chapter 3.

CHAPTER 3: METHODOLOGY & DATA COLLECTION

This chapter provides a description of the study process used in this thesis. The data collection system using LIDAR technology is detailed followed by a description of the study sites. Finally, the statistical methods are outlined.

Data Collection Process

A Pro Laser III LIDAR gun, shown in Figure 10, was connected to a laptop computer via a serial port to facilitate data collection. Along with a laser data transfer program, the computer is capable of receiving data in real-time from the LIDAR gun. Each data line contains time, speed of target, and distance of target. Data can be collected in intervals as small as one-tenth of a second. Figure 11 displays the first day of data collection with the equipment described above. Because of the high visibility presented by the hard hat and vest, they were not used on any of the subsequent data collection days. The picture in Figure 11 was taken west of the Alabama Street traffic signal.

Figure 10. Picture of the Pro Laser III LIDAR gun

Figure 11. Picture of the first day of data collection

Description of Study Sites

Four study intersections were chosen for this study. To minimize variability, the four intersections were chosen because they were located on the same corridor. The location along the corridor ensured the traffic type, volume, and pattern would remain constant throughout the study. The map of the study sites is found in Figure 12. The four intersections were also chosen because of similar geometries to one another. Two intersections possessed CDTs and were of comparable geometries to two intersections which had the flashing hand PSH.

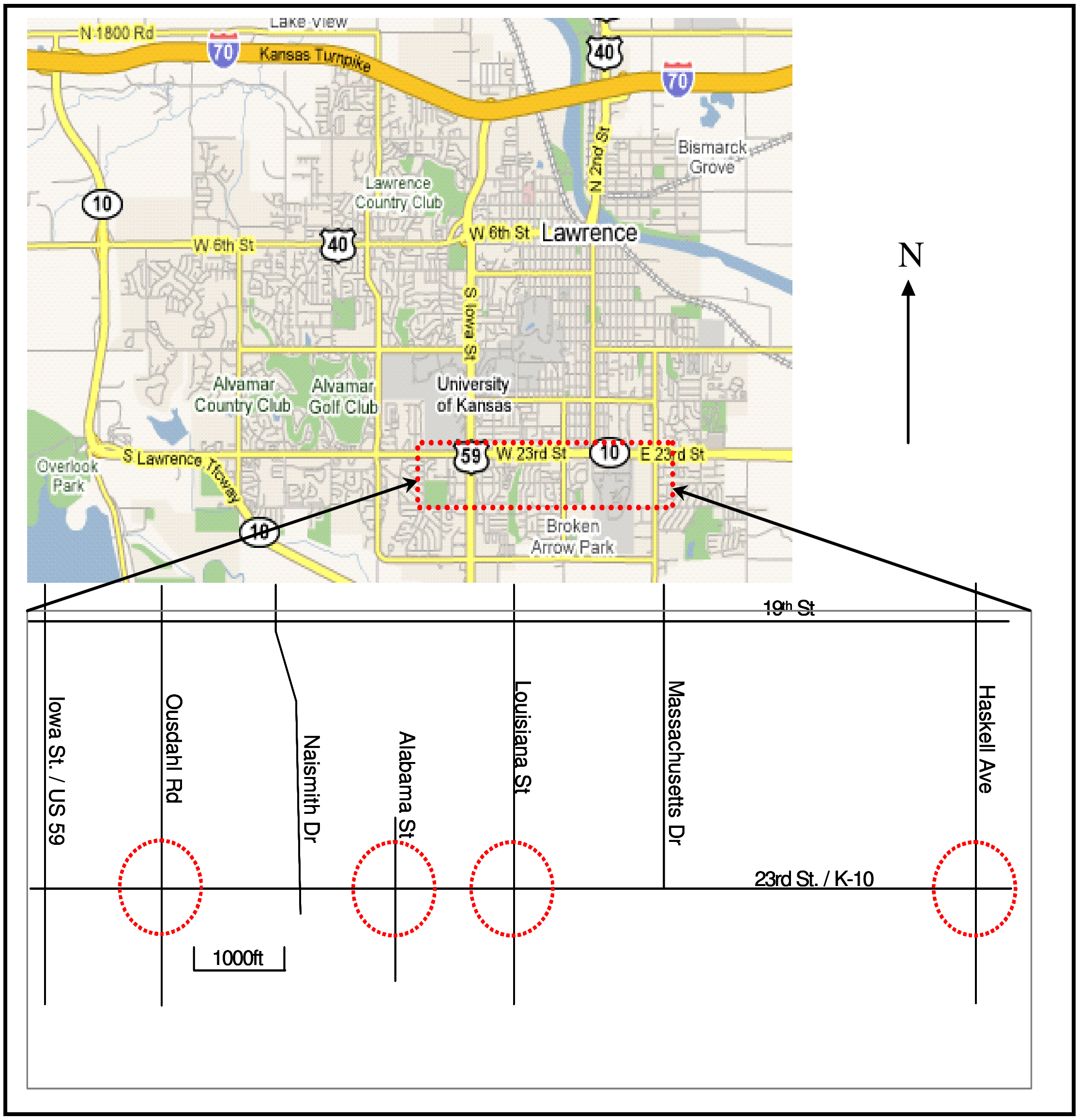

Figure 12. Map of collection points.

Haskell Avenue and 23rd Street, as seen in Figure 13, is a typical four-way intersection commonly found in the Midwest. As discussed, 23rd Street has the functional classification of an urban arterial. This intersection is the second intersection heading west once you enter Lawrence. This is of some importance because east of Lawrence, 23rd Street becomes an access controlled facility with a 70-mph speed limit. Because of the intersection's close proximity to the transition from freeway to an urban arterial, Haskell Avenue has a higher approach speed limit, 45 mph, than the other three study intersections. The 45 mph approach speed results in a 4.5 second amber phase of the traffic signal.

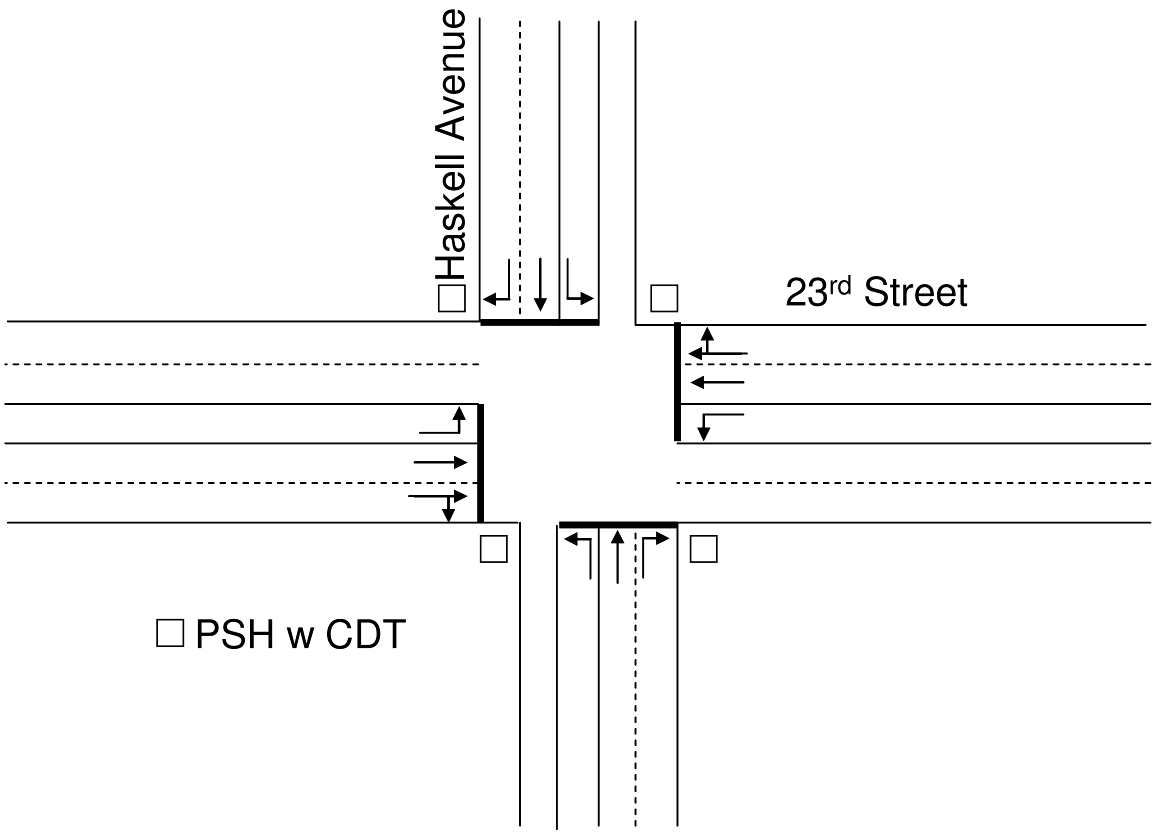

Figure 13. Haskell Avenue and 23rd Street intersection

Haskell Avenue acts as an urban collector serving both residential and commercial areas north and south of the intersection. There is also a noteworthy truck movement to the south on Haskell Avenue where multiple trucking warehouses are located. The traffic signal cycle is an actuated eight phase cycle with a leading left for all four left movements. There is a 4.5-second amber phase. Pedestrian traffic is controlled by CDTs for all movements at all four corners. The pedestrian clearance interval (also what the CDT displays) for the east-west pedestrian movement has a duration of 18 seconds.

Louisiana and 23rd Street, as seen in Figure 14, is also a typical four-way intersection. Louisiana Street, similar to Haskell Avenue, acts primarily as an urban collector serving residential areas both north and south of the intersection. There are public schools north and south of this intersection, which cause a peak interval during school days around 3 p.m. until 4 p.m. The speed limit at 23rd Street is 35-mph on both its approaches to Louisiana Street. The traffic signal cycle is an actuated eight phase cycle with a leading left for all four left movements. There are 4.0-second amber phases. At all four corners, pedestrian traffic is controlled by flashing hand PSHs for all movements. The pedestrian clearance interval (how long the flashing hand is operating) for the east-west pedestrian movement has a duration of 23 seconds.

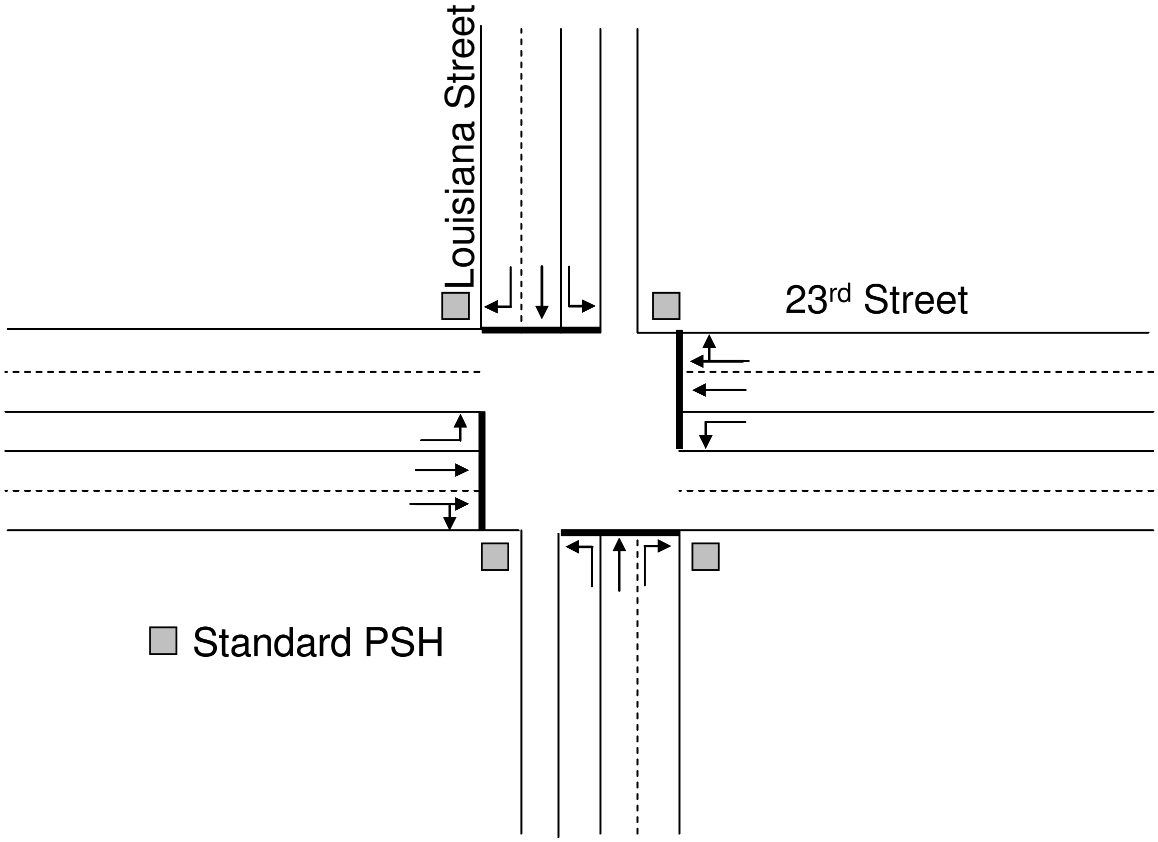

Figure 14. Louisiana Street and 23rd Street intersection

Alabama and 23rd Street, as seen in Figure 15 is also a typical four-way intersection. It is located two blocks to the west of Louisiana Street. Alabama Street acts as a minor collector for the residential areas both north and south of the intersection. Alabama Street extends a few blocks to the north and about one-half mile to the south so all traffic is residential with very little cut-through traffic. The approach speed limit on 23rd Street is 35-mph. The traffic signal cycle is a semi-actuated six phase cycle with a leading left for the 23rd Street left turn movements.

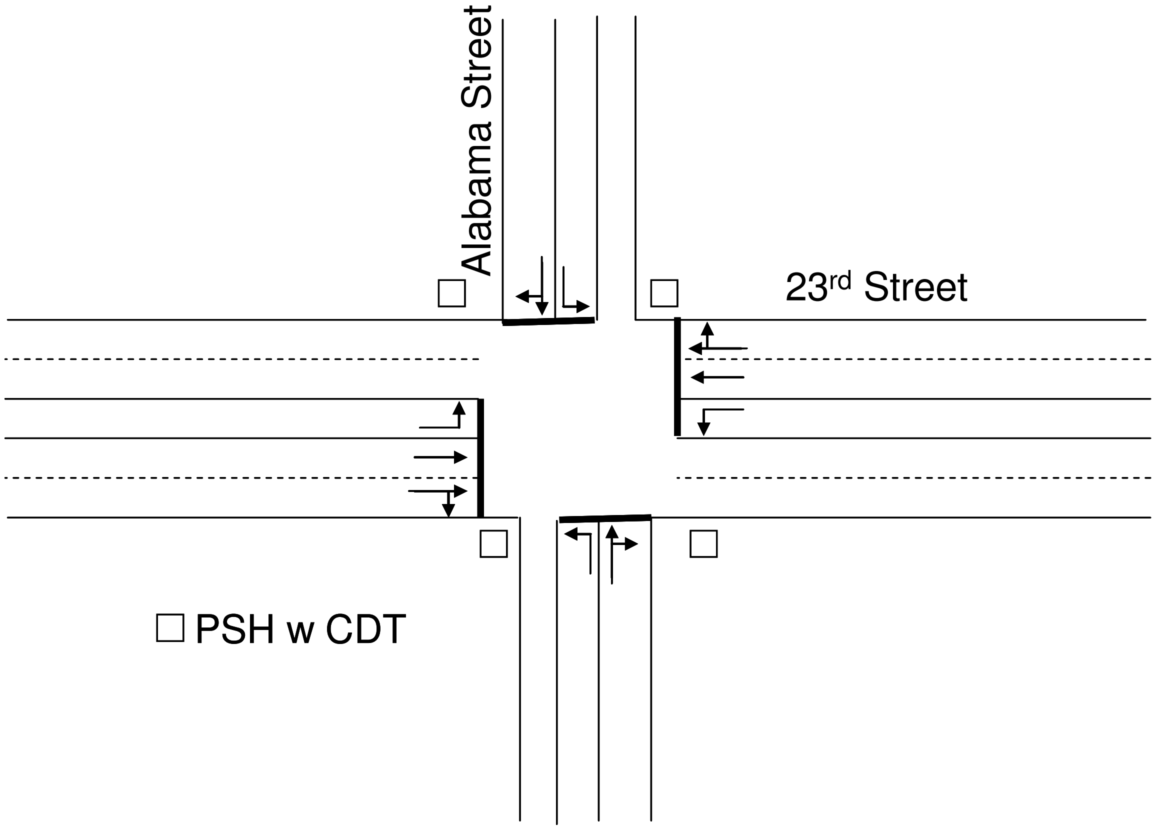

Figure 15. Alabama Street and 23rd Street intersection

At some times near peak periods, the traffic signal at 23rd Street and Alabama Street coordinates with primary traffic signals along the 23rd Street corridor, such as the Louisiana Street traffic signal. There are 4.0-second amber phases. Pedestrian traffic is controlled by flashing hand PSHs for all movements at all four corners. The pedestrian clearance interval for the east-west pedestrian movement has a duration of 15 seconds.

Ousdahl Road and 23rd Street, as seen in Figure 16, is much like the other three sites described above. It is located directly to the east of a major intersection in

Lawrence, 23rd Street and Iowa Street (US 59). Ousdahl Road acts as a minor collector for the residential areas both north and south of the intersection. Ousdahl Road exists a few blocks to the south and most traffic from that approach is residential with little cut-through traffic. To the north of the intersection, there is a public school as well as the main campus of the University of Kansas, which has an impact on traffic during days when school is in session.

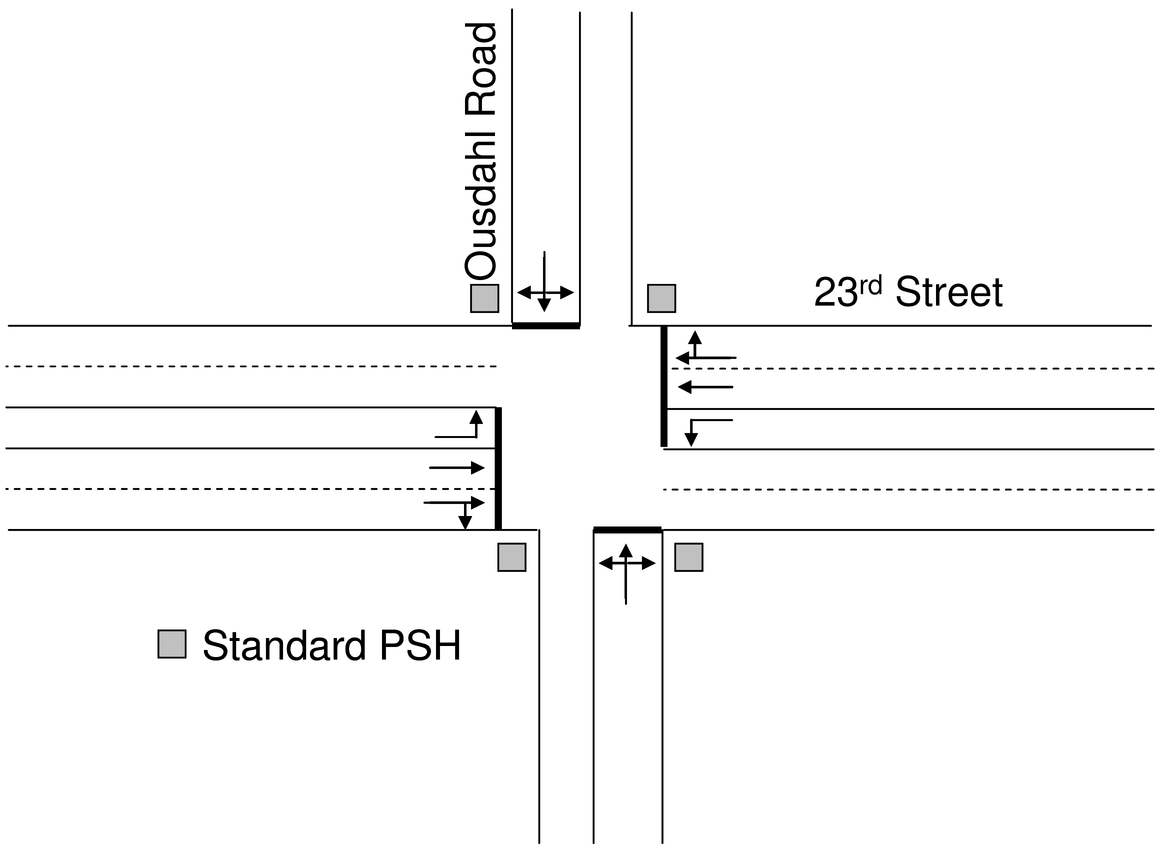

Figure 16. Ousdahl Road and 23rd Street intersection

The speed limit on 23rd Street is 35-mph on both approaches to Ousdahl Road. The traffic signal cycle is a semi-actuated six phase cycle with a leading left for the

23rd Street left turn movements. During some periods of time near peak periods, the traffic signal coordinates with the intersection of 23rd Street and Iowa Street. There are 4.0-second amber phases. Pedestrian traffic is controlled by flashing hand PSHs for all movements at all four corners. The pedestrian clearance interval for the east-west pedestrian movement has a duration of 15 seconds.

TABLE 1 shows the characteristics of each intersection. The intersections all have automatic pedestrian calls during the traffic signal cycle at all times during the day. This means that the pedestrian phase restarts with every new cycle. The coordination along the corridor did cause some noticeable changes in the Alabama Street and Ousdahl Road traffic signal cycles, but any irregularity was noted and data were not collected during these times.

Table 1 Properties of Intersections

Minor Street Intersecting with 23rd Street	CDT Presence	Amber Phase (sec)	Pedestrian Warning Phase (sec)	23rd Street Speed Limit (mph)
Ousdahl Road	No	4.0	15	35
Alabama Street	Yes	4.0	15	35
Louisiana Street	No	4.0	23	35
Haskell Avenue	Yes	4.5	18	45

One peculiarity between the four intersections is that the pedestrian warning phase is substantially longer for Louisiana Street, 23 seconds, to that of Haskell Avenue, 18 seconds. Haskell Avenue has a much longer east-west curb-to-curb distance than that of Louisiana Street. The main difference other than curb-to-curb distance is that Louisiana Street does not have a CDT. The curb-to-curb distances are listed in Table 2.

Table 2 Curb-to-Curb Distances

Intersecting Street	North Crosswalk Distance (ft)	South Crosswalk Distance (ft)
Ousdahl Road	30	35
Alabama Street	51	57
Louisiana Street	49	78
Haskell Avenue	81	69

For each intersection, a location downstream of the intersection was identified from where data could be collected. Each data collection site had visibility of the PSH and traffic signal, was inconspicuous to the oncoming traffic, and was at a place where the oncoming vehicles were visible no less than 500 ft upstream. In all but two locations, (Ousdahl Road westbound and Alabama Street westbound), sufficient cover was found to deem the data collector invisible to oncoming vehicles. No data were collected at the two locations where obstructions were not found. With the exclusion of Ousdahl Road westbound and Alabama Street westbound, data were collected at six different approaches; Ousdahl Road eastbound, Alabama Street eastbound, Louisiana Street east and westbound, and Haskell Avenue east and westbound.

For a subject vehicle to be a valid target, the vehicle had to satisfy the following requirements: it had to be free flowing (at least five seconds headway in front of the vehicle), on the east-west through movement, and be within in the indecision zone after the PSH had been activated. Figure 17 is a picture of the data collection location at the Alabama Street intersection. A vehicle such as the SUV (shown circled) would be described as a typical free flow vehicle found along the corridor and would likely be considered for data collection had it been upstream of the intersection while the CDT had been activated.

Figure 17. Downstream of the Alabama Street study site showing a typical free flowing vehicle

Time of day was also a factor in collecting data for this study. To minimize irregularities, data collection was done at non-peak times during the day. For the corridor, those times were 9:30 a.m. to 11:45 a.m. and 1:30 to 3:00 p.m. The 3:00 p.m. end time was selected to avoid school-related traffic in the area caused by the multiple nearby schools. During the summer, data collection was extended to 4:00 p.m. To eliminate external variables, data were collected when the streets were clean and dry. The days during the weekend were eliminated as well as Monday and Friday because of a possible "non-typical" travel behavior associated with the weekend. All weeks which had major holidays were eliminated so that no unusual data would be collected. The goal was to capture as many "normal" familiar drivers as possible.

The question of driver behavior modification based on the data collection was addressed after the first day of data collection. Figure 18 is a picture from a vehicle traveling westbound on 23^{rd} street through the Louisiana Street study site. As seen in the picture, the driver cannot see the data collector. Figure 19 is a picture taken moments after that of Figure 18. A dotted circle is shown around the data collector to display how inconspicuous the location was.

Figure 18. Data location at Louisiana Street and 23rd Street intersection study site

Figure 19. Data location at Louisiana Street and 23rd Street intersection study site

Statistical Study Design

The CDTs each had nominal 8-inch character height, which conservatively correlates to a 400-foot reading distance for drivers with typical vision, assuming 50 feet of reading distance for every inch of letter height (16). If a driver was likely to change his/her speed based on the information provided by the CDTs, it would happen at some point within 400 feet upstream from the intersection. The data were analyzed to determine if there were more changes in speed during this range when CDTs were present.

For each vehicle, data were also collected on the ultimate decision the driver made (stop or go) and the status of the pedestrian display when the vehicle was 400 feet upstream. Each driver action was categorized based on whether the intersection that it passed through had a CDT or not. The driver actions were subdivided into five categories:

- stopped (began decelerating at or after the beginning of the amber phase),
- stopped but began decelerating early (a 2+ mph change in speed *before* the beginning of the amber phase),
- continued on typically through the intersection, (no change in speed before or after the onset of the amber phase)
- continued on through the intersection but accelerated more than 2+ mph from their approach speed in order to do so, and
- continued on through the intersection but ran the red light (entered the intersection after the onset of the red phase) in order to do so.

There was only one observed instance of red-light running, and so this driver action category was removed from analysis. In order to determine whether these distributions were different based on the presence or absence of CDTs, a Chi-Square analysis (18) was conducted to test the following hypotheses:

Test 1:

H_0: There is no difference in driver actions based on the type of PSH present at the intersection {CDT, flashing hand PSH}.

H_A: There is a difference in driver actions based on the type of PSH present at the intersection.

To further test the data, a Student's t-test was conducted to test whether or not the presence or absence of CDTs changed a driver's behavior with regards to the speed and distance before the amber phase. The data used in these tests were drivers who exhibited a change in speed before the onset of the amber phase. The test hypotheses were:

Test 2:

H_0: There is no difference in driver approach speed based on the type of PSH present at the intersection {CDTs, Flashing hand PSHs} and result (Stop or Go).

H_A: There is a difference in driver actions based on the type of PSH present at the intersection.

Test 3:

H_0: There is no difference in the distance at which drivers changes their approach speed based on the type of PSH present at the intersection {CDTs, Flashing hand PSHs} and result (Stop or Go).

H_A: There is a difference in driver actions based on the PSH type and resulting driver action.

The Student's t-test could not be used on the time remaining data because the data were in integer form. To determine if the sample of flashing hand PSHs differed from that of the CDT, the median test was used (17).

Test 4:

H_0: There is no difference in the time remaining before the onset of the amber phase at which a driver changes their approach speed based on the type of PSH present at the intersection {CDTs, Flashing hand PSHs} and result (Stop or Go).

H_A: There is a difference in driver actions based on the intersection type and result.

It was desired to have a Student's t-test conducted to see if there was a difference in approach speeds for a typical driver at locations with a CDT compared to locations with a flashing hand PSH. A typical driver would change their speed after the onset of the amber phase or proceed through the intersection if there was adequate time. However, the test was aborted because the nature of Haskell Avenue's higher approach speed skewed the data.

Data Collection Plan

Data collection started on April 4, 2007 and ceased on November 11, 2007 with 25 unique days of collection. Because data collection relied on a free flow vehicle at the end of the signal cycle, only one vehicle per cycle could be recorded at best. There were many cycles where no free flow vehicle was present or an irregularity was present (researchers observed an emergency Hazmat operation as well as broken down semi-trucks). Researchers sat through an estimated 1000+ cycles to get the data points presented in this thesis.

The difficulty of collecting data meant that approximately 20 usable data points could be obtained during the period of 9 a.m. -12 p.m. each data collection day. It was possible to collect data after 1 p.m. but the efficiency was much lower on account of the higher volume of traffic.

There were 368 data points collected using the required criteria. Of those 368 data points, 237 data points were able to be analyzed at the point 400 ft upstream from the stop line. The remaining 131 data points were disregarded from Test 1 because they do not possess data at 400 ft from the stop line where it was deemed that a driver could read the CDT (16). Without data at the 400 ft line, it was not possible to examine how the drivers changed their behavior on the basis of the sight distance for the PSH.

The full 368 data points were used for all other analyses. The velocity curves associated with each vehicle were plotted for analysis of the behavior of drivers.

CHAPTER 4: DATA REDUCTION

Raw data were stored as a text file in the form of sequential lines with speed, time, and distance from the LIDAR device. At the end of each data sequence, a note was recorded with the action taken; go or stop, and if the vehicle classification was different than that of a standard automobile. The data file was exported to Microsoft Excel where the data were reduced and placed into individual cells with reference to time, distance, and speed.

The time recorded by the computer was normalized with respect to the PSH. To do this, the LIDAR data stream was terminated upon appearance of the red phase of the traffic signal. That occurrence, with amber phasing duration, made it possible to synchronize the end time of the last data sequence as 0:00:00. The difference of all other data could be related to the end time, and, therefore, could be related to how much time was remaining on the PSH. Unfortunately, this was not always possible, especially with the non-CDT traffic signals and 61 data points were unable to be synchronized with the traffic signal and were, therefore, removed from subsequent analysis.

Distance from the data collection point was recorded, not the distance from the stop line or PSH. To compute the distance from the stop line, the first data point of any collection day was that of a car at rest at the stop line. The distance from the LIDAR gun to the stop line was simply subtracted from the distance listed on each line in the Excel file. The PSH location was referenced to the stop line as well so a distance from the vehicle to the PSH could be figured.

Speed data were collected and used as an indication of bad data. Where there was a clear data stream with a steady speed, outlier speeds were cleaned from the data. During data collection there were instances of a vehicle turning into the path of the laser which would change the speed and distance recorded for a small amount of time before the original target was reacquired. This was typically in instances when the LIDAR was used to collect data on a vehicle in the inside lane and a closer vehicle in the outside lane momentarily obstructed the researcher's view. Outlier speeds in an individual data stream were thrown out for the goal of keeping the data interference to a minimum.

Change in speed was determined by looking through each data stream. If a change in speed was detected, the first instance of the change would be noted so as to record the distance from the stop line, time on the PSH, and action.

For the Student's t-test, the modified behavior described above was placed into separate bins according to their result and if there was or was not a CDT present at the intersection. The actual test was performed in Excel as a two-tailed Student's t-test with the samples having unequal variance (known as type 3 in Excel).

The last t-test, testing typical behavior, was done using data from drivers who did not modify their behavior before the onset of amber. These data were also placed into separate bins and tested in the same way as with the modified behavior drivers.

Data

The 368 data points were sorted into separate bins according to the location of the study site. There were four study sites with two approaches for each site, however there were no data from the Alabama Street westbound and Ousdahl Road westbound intersections so two bins have no data in them.

The apparent bias to Alabama Street was caused by the fact that data were easier to record at the lower-volume intersection. Ousdahl Road proved to be a difficult site to collect data because of the timing with the adjacent intersections: the well-coordinated traffic signals meant that few free flowing vehicles arrived near the end of the clearance interval. Equal time was spent at all six sites but they did not yield an equal number of data points.

Table 3 General Classification of Data

Intersection	Westbound	Eastbound
Alabama Street	121	0*
Ousdahl Road	53	0*
Haskell Avenue	49	36
Louisiana Street	55	54
Total	368	

*No data were collected here because the researchers could not find an inconspicuous data collection location.

CHAPTER 5: ANALYSIS

This chapter provides the analysis used in this thesis. The data collected were reduced and tested as described earlier in Chapter 3. The data were first tested for behavior in an actual time versus estimated time plot to understand the different types of behavior. Next, the data of drivers that increased or decreased their speed were graphed as a speed profile to examine just when the behavior occurred. The entire data population was also tested to look for any differences between intersections with flashing hand PSH and those with CDTs.

Time versus Estimated Arrival Time

The graph in Figure 20 shows the collected data plotted as an actual time versus estimated time relationship. The x-axis is the actual time remaining until the traffic signal begins its amber phase. This is the time displayed on the CDT or, in the case of a flashing hand PSH, it is the time remaining until the hand changes from flashing to steady. The y-axis is an estimated time to the intersection based on each vehicle's speed at 400 ft upstream from the stop line. The line originating at (0, 0) has a slope of one representing a time-time relationship for the beginning of the amber phase. For example, if a vehicle is 400 ft upstream from the stop line with 6 seconds remaining, and that driver is going 45 mph, then the vehicle will reach the stop line at the onset of the amber phase. Data points with a "go" result above this line mean that a driver has modified his/her behavior by increasing speed or risk running the red light. The line originating at (0, 4) has a slope of one to represent the time-time relationship for the onset of the red phase. This line functions the same as the one originating at (0, 0) in that, if a vehicle going 45 mph is 400 ft from the stop line with two seconds displayed on the CDT and the driver does not change speed, then the vehicle will reach the stop line at the onset of the red phase, except at Haskell Avenue which provides an extra 0.5 seconds of clearance interval.

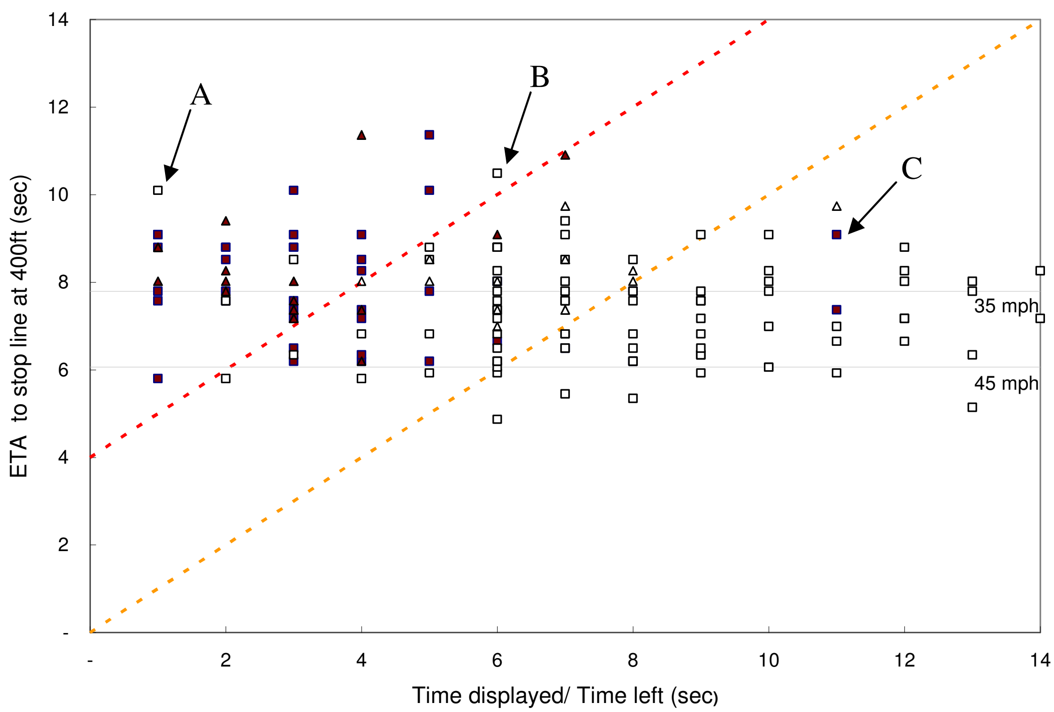

Figure 20. Actual time vs. estimated time of arrival

The color of the data points corresponds with the ultimate driver behavior: the lighter of the two colors is “go” and darker is a “stop” result. A data point in the shape of a square originated at a traffic signal equipped with a CDT. Data points with a diamond shape originated from traffic signals which were equipped with standard flashing hand PSHs. There was only one instance of red-light running during the entirety of the data collection. That instance is indicated in Figure 20 as “A”.

This graph was used to indicate modified behavior from drivers. A data point, such as data point “B”, was a vehicle which consequently went through the intersection. If that vehicle had stayed at a constant rate, they should have stopped or would have run the red light. Because there was only one identified instance of red-light running, it can be deduced that this vehicle accelerated in order to proceed through the light without running the red.

Alternatively, data points such as “C” were identified because they were unusual in that they stopped at the intersection: if the vehicle had remained at a constant speed, based on their speed when 400 ft from the stop line, then they would have been able to pass the stop line before the onset of the amber phase. These drivers were classified as “aggressive decelerators” because of their overly-conservative nature. Earlier referenced research (13) coined a similar term when they classified a group as “Conservative stop – Drivers who took the stop action even though they could have proceeded through the intersection during the yellow phase.” So this behavior has been observed in previous trials by different researchers in different locations (the cited research was done in Maryland).

Data points similar to “B” and “C” were graphed into a speed profile. Figure 21 displays the speed profiles of those drivers similar to “B”, labeled as aggressive drivers. The large diamonds represent the position of each vehicle at the onset of the amber phase.

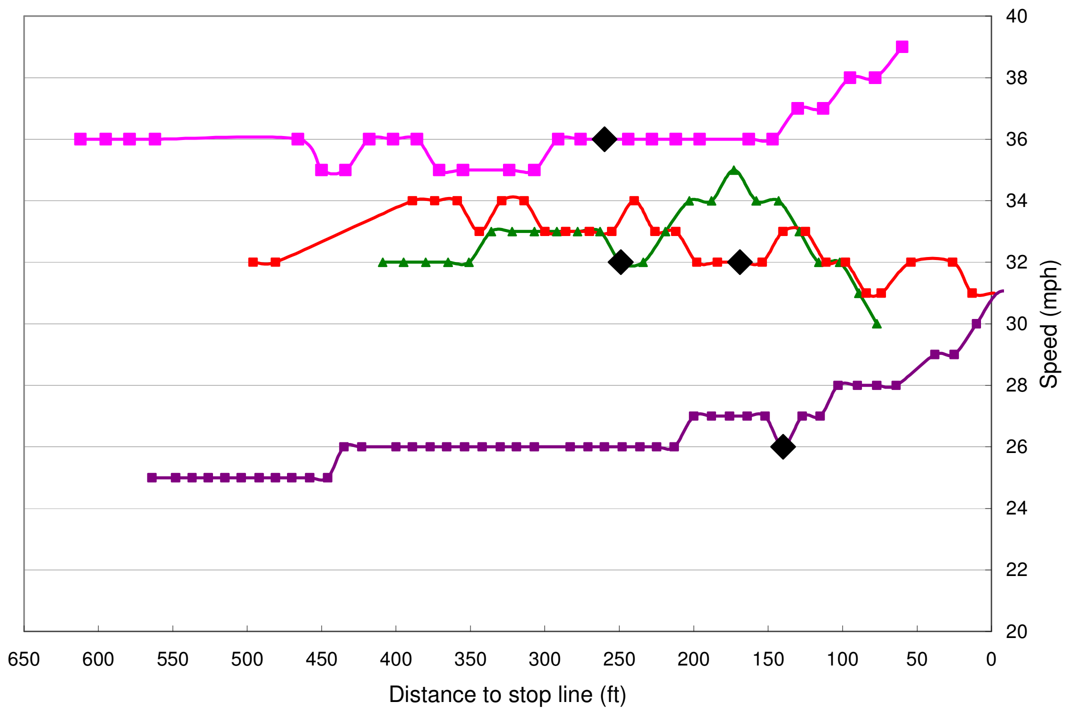

Figure 21. Speed profile for aggressive drivers

One aggressive decelerator's speed profile is displayed in Figure 22. Again, the large diamond represents the vehicle's position at the onset of the amber phase. The speed profile suggests that the driver started braking <u>before</u> the onset of the amber. The driver's motivation is unknown, but that driver likely had to have some auxiliary information to come to that decision.

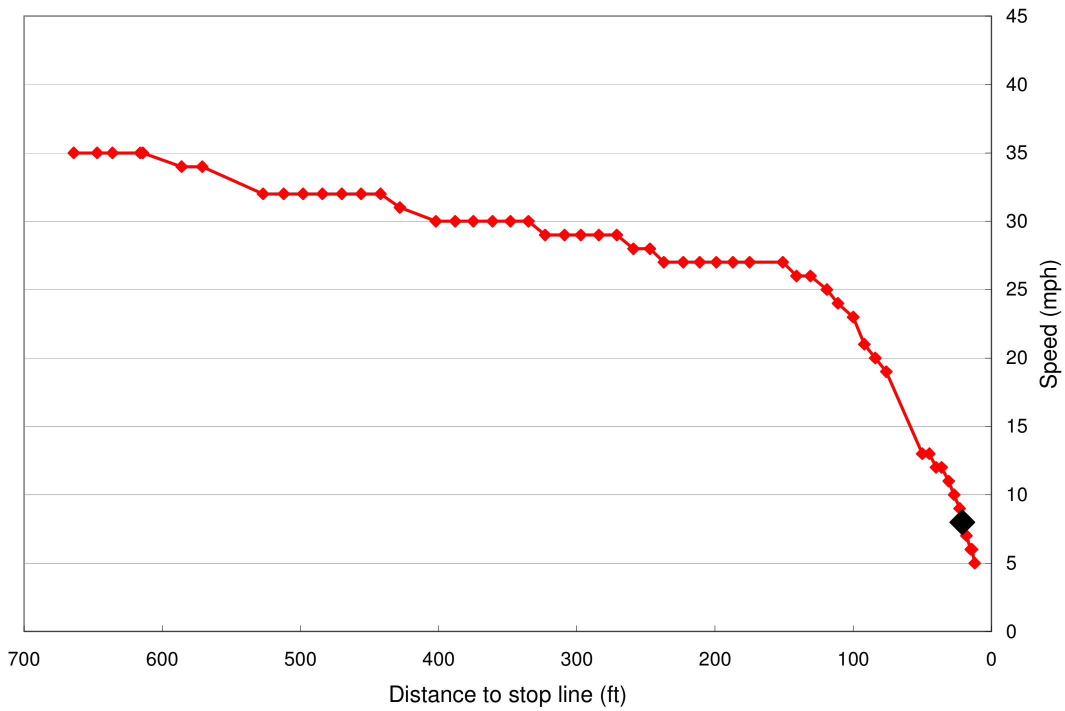

Figure 22. Speed profile for aggressive decelerators

The speed profile shown in Figure 23 is that of the one occurrence of red-light running by a vehicle. The occurrence at Alabama Street westbound was the 360th data point collected. Until that time, there had been no red-light running observed. As in Figure 21 and Figure 22, the large diamond indicates the onset of the amber phase for the traffic signal, in this case, Alabama Street and 23rd street. The speed limit of the approach is 35 mph yet the first data point collected is much lower at 26 mph. This driver did start accelerating at a steady rate <u>before</u> the onset of the amber phase and continued to accelerate up to the speed of 35 mph. The acceleration behavior suggests that the driver had already made the decision to go before the onset of the amber phase.

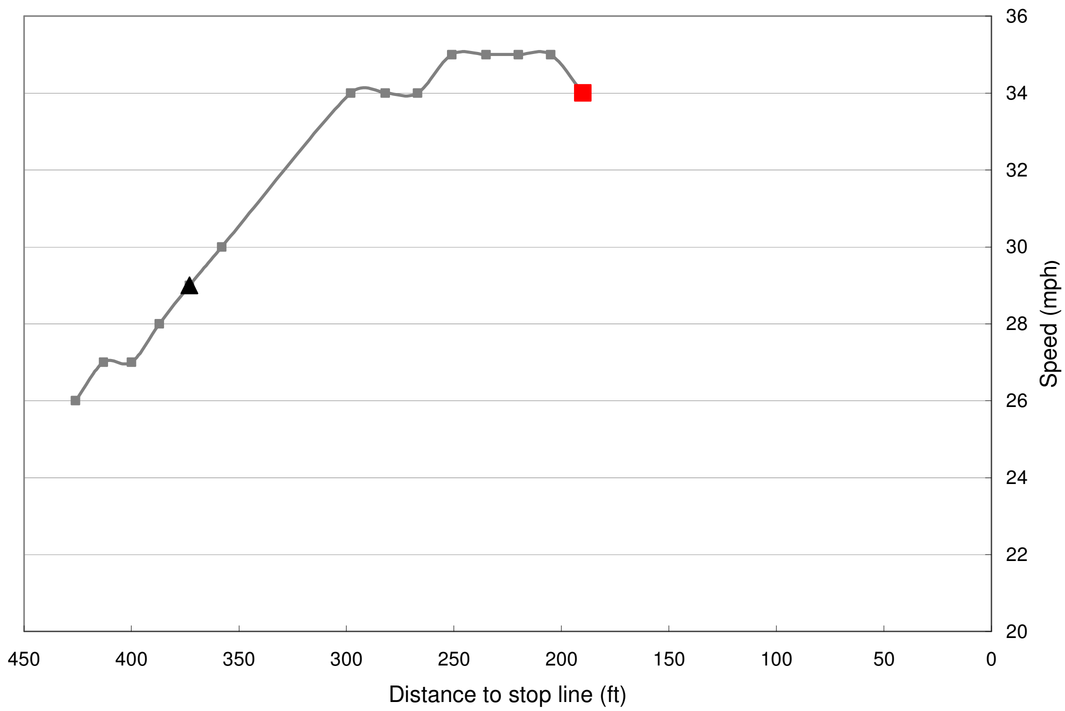

Figure 23. Speed profile of a red-light runner

Comparison of CDT versus Flashing Hand PSH Locations: Test 1

The data were tabulated in Table 4 by the type of PSH at the intersection and by the drivers' approaching behavior. Drivers were classified in the "Accelerated During Go" column if a 2 mph increase from the 400ft speed was observed before the vehicle reached the stop line. Data points were placed in the "decelerated early" column if the vehicle began to decelerate <u>before</u> the onset of the amber phase.

Table 4 Cross Classification of Driver Action by the Presence of Pedestrian CDTs

	Unchanged Stop	Stop, Early Deceleration	Unchanged Go	Accelerated During Go	Total
Pedestrian CDT	54[A] (57.10)[B]	17 (16.23)	112 (104.68)	23 (27.99)	206
Flashing Hand PSH	48 (44.90)	12 (12.77)	75 (82.32)	27 (22.01)	162
Total	48	12	187	50	368

[A] The top number in each cell is the observed value.
[B] The bottom number each cell is the expected value based on total observations.

The preliminary results show that at CDT locations, a driver was less likely to accelerate and more likely to decelerate early if they would not be able to reach the stop line before the beginning of the clearance interval. Using a chi-squared test for independence (18), it was found that the difference in drivers who accelerated between the flashing hand PSH was not statistically significant at the $\alpha = 0.05$ level, therefore, the null hypothesis cannot be rejected.

A cell-by-cell comparison of adjusted residuals between the observed and expected frequencies was also conducted in order to better understand the nature of the data, shown in Table 5. This was done in order to determine if any parts of the distributions were close to being significantly different from the expected values; any adjusted residuals with an absolute value of about two or three indicated a significant difference between the observed and expected observations for the given cell (18). None of the adjusted residuals have an absolute value greater than or close to two so there is not a statistically significant difference (or even one that is nearly so) between the columns.

Table 5 Adjusted Residuals for Testing Independence

	Unchanged Stop	Stop, Early Deceleration	Unchanged Go	Accelerated During Go
Pedestrian CDT	-0.73	0.03	1.54	-1.53
Flashing Hand PSH	0.73	-0.03	-1.54	1.53

Comparison of Behavior Based on Speed: Test 2

Two separate tests were run to determine if the approach speeds were different for CDT locations versus locations with a flashing hand PSH. All drivers tested were those who had modified their behavior before the amber phase. These drivers were singled out because it was thought these drivers likely had outside interaction and perhaps would have been more likely to have received information from the CDT. The data were sorted based on those drivers' results, "go" or "stop." The test data and result can be found in Table 6.

Table 6 Student's t-test Result for Comparison of Approach Speed for Drivers with Modified Behavior

	Modified behavior with a "go" result		Modified behavior with a "stop" result	
	Flashing Hand PSH locations	CDT locations	Flashing Hand PSH locations	CDT locations
Sample	12	17	8	23
Average approach speed before drivers modified behavior (mph)	32.5	34.6	36.4	35.9
p-value	0.2591		0.8449	

There were 12 drivers at flashing hand PSH locations and 17 drivers from locations with CDT who proceeded through the intersection. The average speeds were 32.5 and 34.6 mph for PSH and CDT, respectively. The t-test found a p-value of 0.2591 which means that the difference in the means is not statistically significant at the $\alpha = 0.05$ level of significance.

Some drivers decided to stop instead of proceeding through the intersection. These drivers were selected because they changed their speeds prior to the amber phase, these drivers were the “aggressive decelerators” described earlier. Test 2 compared samples of 8 and 23 drivers at PSH and CDT intersections, respectively. These samples had averages of 36.4 mph for PSH locations and 35.9 mph for CDT traffic signal locations. These averages, when tested, resulted in a p-value of 0.8449 which is not statistically significant which means the null hypothesis is not rejected.

Drivers’ speeds at the two types of intersections were not statistically different, which means the installation of the CDT does not appear to affect approach speed. This is different than what is commonly believed (10) when a CDT is installed. An increase in speed would imply a decrease in safety, but none was found.

Comparison of Behavior Based on Distance: Test 3

A second type of criteria was tested to check the distances from the stop line where drivers modified their behavior. Data were separated into two bins according to the end result “go” or “stop.” Again, the population was made up of drivers who changed their behavior before the onset of the amber phase. The actual distance was calculated from the stop line and is based on the LIDAR gun’s final reading for each vehicle. The test data are shown in Table 7.

For the test for modified “go” results, the sample sizes for flashing hand PSH and CDT locations were 12 and 17, respectively. The samples had an average distance of 418.4 ft and 300.4 ft, respectively. The Student’s t-test was run and a p-value of 0.0242 was obtained causing the rejection of the null hypothesis indicating that there was a significant reduction in the distance from the stop line at which a speed increase was observed.

Table 7 Student's t-test Result for Comparison of Distance at which Modification Occurred

	Modified behavior with a "go" result		Modified behavior with a "stop" result	
	Flashing Hand PSH locations	CDT locations	Flashing Hand PSH locations	CDT locations
Sample	12	17	8	23
Average distance where drivers modified behavior (ft)	418.4	300.4	169.3	309.7
p-value	0.0242		0.0237	

The "stop" bins, with eight and 23 samples for PSH and CDT locations, showed an average distance of 169.3 ft and 309.7 ft. The p-value for this test was 0.0237, which also caused a rejection of the null hypothesis, indicating that the two locations have different mean distances.

Although both of these distance tests yielded p-values, which caused a rejection of the null hypothesis, these rejections were distinctly different. The "go" test had a higher mean, 418.4 ft, for the flashing hand PSH locations than the mean for the CDT locations, 300.4 ft. Conversely, the "stop" test had a higher mean for the CDT locations, 309.7 ft, versus the flashing hand PSH locations, 169.3 ft. These results imply that the drivers who proceeded through intersections made their decisions farther downstream when a CDT was present and drivers who decided to stop began slowing sooner when the CDT was present.

The apparent trend in the data could support mean one or both of the following theories:

- The installation of the CDT reduces or possibly eliminates the traditional indecision zone for drivers who look for the information.
- The presence of CDTs at an intersection appear to positively alter the distances upstream of the intersection when drivers decide to go or stop.

Comparison of Behavior Based on Time

The final test (17) using data from drivers who modified their speeds before the onset of the amber phase was to test whether or not drivers changed their behavior based on the time displayed on the CDT versus the flashing hand PSH. The test data were rounded to the nearest second because of the accuracy of time displayed on the CDTs was dependent on the person doing the data collection and one-second precision was considered the most accurate the data collector could achieve. The test data for drivers who proceeded through the intersection can be found in Table 8. Drivers who stopped were tested in Table 9. The critical t-value at the $\alpha = 0.05$ level is 3.841 (17).

The test bins were the same as for tests 2 and 3. Since the flashing hand PSHs do not display a time, it would be difficult for drivers to know how much time remains until the amber phase began. Drivers may be familiar enough with the traffic signal to know how much time is remaining based on the fact that the number of flashes remains constant throughout the cycle and they can deduct time if they see the start of the pedestrian clearance interval.

Table 8 Student's t-test Result for Comparison of Time Remaining at which Modification Occurred for Drivers who Proceed through the Intersection (go)

	Flashing Hand PSH	CDT	Sample
> 2 seconds	4	10	14
≤ 2 seconds	8	7	15
Sample	12	17	29
t-statistic	1.8304		

The median time for the "go" test was 2 seconds for the population at all intersections. The median test found that the t-value for the two different samples was 1.8304. This is less than the 3.841 t-value needed for statistical significance, so the test failed to reject the null hypothesis that the two medians were the same.

The case was much the opposite for data shown in Table 9. The sample population of drivers choosing to stop had a median time of 5 seconds. These data yielded a t-value of 7.7874, which is statistically significant because it is higher than the critical value of 3.841. The null hypothesis is rejected, indicating that the median time remaining in the pedestrian clearance interval when an “early decelerator” begins to stop, is different between PSHs and CDTs. The rejection of the null hypothesis implies that there is a significant difference in driver behavior for “early decelerators” based on the two types of pedestrian treatments.

Table 9 Student’s t-test Result for Comparison of Time Remaining at which Modification Occurred for Drivers who Stopped at the Intersection (stop)

	Flashing Hand PSH	CDT	Sample
> 5 seconds	0	13	13
≤ 5 seconds	8	10	18
Sample	8	23	31
t-statistic	7.7874		

The mean time at which 23 drivers at CDT locations started to slow down was 6 seconds while the mean time for the 8 drivers at PSH locations was 2 seconds prior to the amber phase. It appears that conservative drivers at CDT-equipped intersections begin slowing well in advance if they know they cannot make the stop line before the onset of the red phase. The other reason could be that drivers at flashing hand PSH locations see the flashing hand and increase their speed to make the red signal. Both of these alternatives suggest that the presence of CDTs have a calming effect on these drivers compared to flashing hand PSHs. This seems to agree with studies (8, 11), which have found that CDT decrease the instances of yellow- and red-light running.

CHAPTER 6: CONCLUSION & RECOMMENDATIONS

In this chapter, a discussion of the preceding analysis is presented. The discussion evaluates whether drivers modify their behavior when a CDT is present, what kind of modification occurs, and if the nature of the driver modification is detrimental to safety.

Key Findings

It was found that drivers may have modified their behavior in one of two ways at CDT-equipped traffic signals. They may 1) accelerate to make the light or 2) begin decelerating before the onset of the amber phase. The data were graphed in an actual time versus estimated time plot to identify the extreme modified behavior. Not every driver modified their behavior at intersections equipped with CDTs. A chi-squared test, (Test 1), indicates that the proportion of drivers who accelerated early was not significantly different at CDT or flashing hand PSH locations. The same test also found that the proportion of drivers who decelerated early was not significantly different at either type of traffic signal.

Modified behavior was pulled from the rest of the population and separated into bins according to their result and location. It was thought that some drivers may modify their behavior no matter what type of PSH was present because they can gather extra information even from the flashing hand PSH. Those drivers would be more familiar or more aggressive drivers. The data were tested using the Student's t-test to determine if any of the parameters were different among those drivers who modified their speed behavior.

Test 2 compared the approach speeds before drivers modified their speed behavior. It was found that the speeds were not statistically different between the two types of PSHs. This was important because one of the CDT intersections, Haskell Avenue, had a higher approach speed limit. Yet, the speeds were not significantly higher with intersections equipped with CDTs. This result indicates that CDTs do not increase approach speeds at traffic signals.

Test 3 examined the distance at which drivers began their modification behavior for flashing hand PSH and CDT traffic signals. In both cases, it was found that for those drivers who proceeded through the intersection and for those who stopped, the difference between flashing hand PSHs and CDTs was statistically significant. At CDT-equipped traffic signals, drivers modified their behavior approximately 300 ft upstream of the stop line whether they proceeded through the intersection or stopped. At flashing hand PSH traffic signals, drivers modified their behavior on average, 169 ft from the stop line for those who went through and 418 ft for those who stopped. The significance here is that the presence of the CDT may modify the indecision zone for the intersection. This is also an indication that drivers, who have more information (from the PSHs), make different decisions from those who do not.

Test 4 did not use a Student's t-test but instead used a Median test (17). The test did not find a significant difference in drivers who proceeded through the intersection. The test did find a significant difference for drivers who stopped. These "early decelerators," were identified in the actual time versus estimated time plot, have shown a significant benefit of the CDT. If a CDT is present those drivers who chose to stop start slowing well before the onset of the amber phase. When a CDT is not present, drivers wait until they are farther downstream and then slow at a greater rate. This pattern may be an indication that the CDT could lower instances of rear-end crashes and decrease fuel consumption. Those ideas cannot be proved in this body of work but coupled with future work, it could be investigated.

The final determination of this thesis is that the presence of a CDT is not detrimental to safety. The CDT is more accepted by pedestrians (6), may improve driver characteristics at the intersection, and does not increase vehicle approach speeds. It is recommended by the author that CDTs be installed at all traffic signals where a PSH is warranted.

Future Work

Any future work to be done in this area must first address the method of data collection. The technique used was a inefficient. During the formation of this study, other more efficient techniques were considered, but were abandoned because of their less precise methodology. These methods included: speed traps, brake observations, and stopping observations. Other methods, such as video, were also abandoned because it is viewed as less accurate then the LIDAR method. Still, there is likely a better system to collect these data and any researcher wishing to study further should first explore other more efficient methods which should allow for more data to be collected.

Some suggested future work involving the study of CDTs includes the study of three different configurations of the PSH; a traditional flashing hand, a CDT, and a PSH which the drivers cannot see. It was thought that one of the reasons no significance between PSHs and CDTs was found in this study is because drivers interact with the flashing hand PSH to a similar degree as the CDT. If a PSH could be hidden from upstream drivers, then a study could be done to see if drivers interact with any PSH, not just a CDT equipped traffic signal.

Crash records should also be scrutinized with relation to the installation of a CDT to look for any safety benefit of the CDT from a vehicular standpoint. To be successful, a CDT must be installed in an already-established traffic signal location with prior crash records. This method should allow sufficient time after the CDTs are installed for the crash record to develop to answer the ultimate question if a CDT changes the safety of the driver.

Any future work should also be supplemented with a driver survey of the locations. During this study, anecdotal conversations with some drivers (not the same drivers studied in this thesis) indicated they interact with the CDTs, but no formal survey has been done, and the actual proportion of drivers who view the CDT is not known.

Finally, work could be done on the opposite end of the traffic signal cycle with reference to start up lost time. It has been suggested that some CDTs may also decrease lost time when stopped drivers look to their right or left to see how much time is remaining until their approach turns green. This may have more effect on longer length cycles where the drivers become impatient and can get more information on the remaining time rather than the nominal information the amber phase gives. This theory is exemplified earlier by Figure 3 which shows a countdown until the onset of the green phase.

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APPENDIX A

Table 10 Chi-Squared Test

	Unchanged	Pre-emp	Unchanged	Accelerate	Sampled
CDT	54	17	112	23	206
No CDT	48	12	75	27	162
Total	102	29	187	50	368

	Unchanged	Pre-emp	Unchanged	Accelerate
CDT	57.10	16.23	104.68	27.99
No CDT	44.90	12.77	82.32	22.01

	Unchanged	Pre-emp	Unchanged	Accelerate
CDT	-0.73	0.30	1.54	-1.53
No CDT	0.73	-0.30	-1.54	1.53

APPENDIX B

Table 11. Data for Tests 2 and 3 of the Student's t-test

	Speed, Go		Speed, Stop		Distance, Go		Distance, Stop	
	PSH	CDT	PSH	CDT	PSH	CDT	PSH	CDT
	24	29	26	23	188	93	28	70
	28	30	33	29	226	124	55	71
	28	30	34	30	335	137	58	131
	29	30	38	31	339	163	118	147
	31	31	38	31	342	270	199	153
	32	32	40	31	424	271	208	229
	32	34	41	32	451	283	299	245
	34	34	41	32	482	285	389	263
	35	35		33	526	289		263
	36	35		33	564	290		268
	37	36		34	566	351		272
	44	36		34	578	360		272
		36		35		378		327
		37		35		381		331
		39		36		385		339
		41		36		491		343
		43		36		556		377
				39				390
				44				419
				45				434
				47				473
				50				633
				50				674
Mean	32.5	34.6	36.4	35.9	418.4	300.4	169.3	309.7
p-value	0.2591		0.8449		0.0242		0.0237	
sample	12	17	8	23	12	17	8	23

Shading of the sample data signify samples for the Haskell Avenue & 23rd Street intersection. Shading of the p-value means the p-value is statistically significant.

APPENDIX C

Table 12. Median Test for Time and Go Result

Time, Go			
Sample	1	2	
> 2	4	10	14
<=2	8	7	15
	12	17	29

Table 13. Median Test for Time and Stop Result

Time, Stop			
Sample	1	2	
> 5	0	13	13
<=5	8	10	18
	8	23	31

APPENDIX D

Table 14 Table Data for Median Test

Median Test				
	Time, Go		Time, Stop	
	PSH	CDT	PSH	CDT
	0:00:00	0:00:00	0:00:00	0:00:01
	0:00:01	0:00:01	0:00:01	0:00:02
	0:00:02	0:00:01	0:00:01	0:00:02
	0:00:02	0:00:02	0:00:01	0:00:04
	0:00:02	0:00:02	0:00:02	0:00:04
	0:00:02	0:00:02	0:00:03	0:00:04
	0:00:02	0:00:02	0:00:03	0:00:04
	0:00:02	0:00:03	0:00:04	0:00:05
	0:00:03	0:00:03		0:00:05
	0:00:03	0:00:03		0:00:05
	0:00:04	0:00:03		0:00:06
	0:00:06	0:00:03		0:00:06
		0:00:04		0:00:06
		0:00:04		0:00:06
		0:00:06		0:00:06
		0:00:09		0:00:07
		0:00:09		0:00:07
				0:00:08
				0:00:09
				0:00:09
				0:00:10
				0:00:12
				0:00:12
Median	0:00:02		0:00:05	
Mean	0:00:02	0:00:03	0:00:02	0:00:06
Sample	12	17	8	23
T-value	1.83		7.79	

Shading of the T-value signifies statistically significant.

APPENDIX E

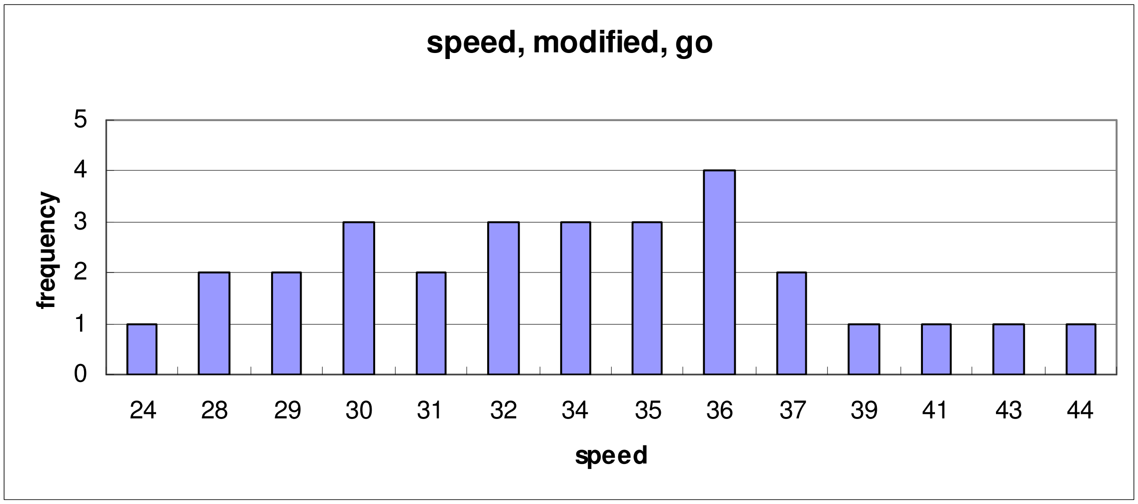

Figure 24. Histogram of data showing normalized data.

BIOGRAPHY

Brandon Bundy grew up splitting his time between Wichita, KS and Kimberling City, MO where he got to live very near Table Rock Lake. After graduating high school in Wichita, he went to the University of Missouri—Rolla in August 2002 where he graduated with a Bachelor of Science in Ceramic Engineering with an economics minor, May 2006. Before starting the master's program at the University of Kansas, he worked a summer as an engineering intern at the City of Branson. In August 2006 he began his Master of Science program at the University of Kansas. Brandon will graduate with a Master of Science degree in Civil Engineering-Transportation emphasis from the University of Kansas.

During his career at the University of Kansas he served in such roles as the race coordinator for the KU Cycling Club and the vice president of the KU Institute of Transportation Engineers. He is also a registered E.I.T. in the state of Kansas with the hope of achieving a P.E. within four years.